

Magnitude and Structure of Urodynamic Change After Posterior Urethral Valve Ablation: An Effect-Size and Principal-Component Analysis of Three Surgical Techniques

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Abstract

Background. Comparisons of surgical techniques for posterior urethral valve (PUV) ablation usually rest on *p*-values for pre- versus postoperative means. A *p*-value confounds the size of a change with the size of the sample and gives no information about how the urodynamic variables move together, which is precisely what distinguishes a technique that relieves obstruction from one that merely shifts a single parameter.

Objective. To quantify the magnitude of postoperative urodynamic change on a scale-free metric, to compare the three techniques on postoperative values directly, and to characterise the dimensional structure of the urodynamic profile.

Methods. Aggregate urodynamic data from 142 boys operated on for PUV were analysed: endoscopic valve resection (*n* = 32), polyethylene valvulotome ablation (*n* = 49), metallic valvulotome ablation (*n* = 61). Eight variables were recorded before and after surgery. Standardised mean differences (Hedges' *g*) with 95 % confidence intervals were computed for every variable and group. Postoperative values were compared between techniques by Welch tests. The 6 × 8 matrix of group–phase profiles was subjected to principal component analysis on standardised variables.

Results. Effect sizes were very large throughout ($|g| > 1.9$ for every variable except maximum bladder capacity). Effective urethral cross-section showed *g* = 4.15, 8.37 and 6.25 in groups I, II and III; the urethral resistance coefficient showed *g* = −2.54, −5.91 and −3.75. Postoperative urethral resistance differed significantly between all three techniques, with metallic valvulotome ablation lowest (0.05 ± 0.02 ; *d* = 1.50 versus polyethylene, *p* < 0.001), whereas post-void residual volume did not differ between techniques (*p* ≥ 0.12 for all pairs). Principal component analysis recovered a single dominant axis accounting for 86.1 % of variance, with post-void residual, wall thickness and urethral resistance loading against flow rate, cross-section, detrusor pressure and detrusor tension. Displacement along this axis was largest for the metallic valvulotome (5.30 units) and smallest for the polyethylene valvulotome (4.03).

Conclusions. The urodynamic response to valve ablation is essentially one-dimensional. Post-void residual volume normalises equally well with all three techniques and is therefore uninformative for technique comparison; urethral resistance and flow rate discriminate between them.

Keywords: Posterior urethral valve; bladder outlet obstruction; urodynamics; effect size; principal component analysis; paediatric urology.

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1. Introduction

Posterior urethral valves are the commonest cause of congenital bladder outlet obstruction in boys and the leading urological cause of chronic kidney disease in childhood [1, 2]. A systematic review of 34 studies covering 1474 boys treated by endoscopic valve resection reported chronic kidney disease in about 22 % and end-stage renal disease in about 11 % of patients [3]. Relief of the anatomical obstruction is therefore a necessary but not sufficient condition for a good functional outcome, and the residual bladder dysfunction that follows ablation evolves over time from detrusor overactivity through reduced compliance to myogenic failure [4, 5].

Because several ablation techniques are in use, the question of which most completely relieves the obstruction is a practical one. It is usually addressed by testing pre- against postoperative means within each technique and reporting the resulting p-values. Two problems follow. First, a p-value is a statement about evidence against a null hypothesis, not about the size of an effect; with $n = 61$ a trivial change reaches significance, while with $n = 32$ a substantial one may not. Comparing techniques by their p-values therefore compares sample sizes as much as clinical effects. Second, testing each variable separately ignores the correlations between them. Bladder outlet obstruction is a single physiological state expressed simultaneously in flow, pressure, residual volume and wall morphology; the appropriate question is how far a technique moves the patient along that shared axis, not how many of eight separate tests it passes.

Both problems have standard solutions. The magnitude of change is expressed by a standardised mean difference with a confidence interval [6, 7], and the dimensional structure of a multivariate profile is recovered by principal component analysis. Neither has been applied systematically to the comparison of PUV ablation

techniques. The present study applies both to a cohort of 142 boys.

2. Methods

Patients and design. This is a retrospective comparative analysis of aggregate urodynamic data from 142 boys operated on for infravesical obstruction caused by posterior urethral valves. Group I underwent endoscopic valve resection ($n = 32$), group II ablation with a polyethylene valvulotome ($n = 49$), and group III ablation with a metallic valvulotome ($n = 61$). Allocation was determined by clinical circumstance and available instrumentation; the study was not randomised.

Assessment. Diagnosis was confirmed by ultrasonography, voiding cystourethrography, uroflowmetry, cystomanometry and urethrocystoscopy. Eight variables were recorded before and after operation: maximum bladder capacity $V_{\max}$ (ml), bladder wall thickness hw (cm), effective urethral cross-sectional area S_u (cm²), post-void residual volume V_r (ml), mean flow rate Q (ml/s), intravesical (detrusor) voiding pressure $p_{\det}$ (cmH₂O), detrusor muscular tension T_d (arbitrary units), and the urethral resistance coefficient K_u (dimensionless).

Effect sizes. For each variable and group the standardised mean difference was computed in the d_{av} form appropriate to repeated measures [7]:

$$d_{av} = \frac{\bar{X}_{\text{post}} - \bar{X}_{\text{pre}}}{\sqrt{\frac{SD_{\text{pre}}^2 + SD_{\text{post}}^2}{2}}} \quad (1)$$

and corrected for small-sample bias by the Hedges factor

$$J = 1 - \frac{3}{4(n-1)-1}, \text{ giving } g = J d_{av}. \text{ Confidence}$$

intervals were obtained from

$$SE(g) = \sqrt{2(1-r) \left(\frac{1}{n} + \frac{d_{av}^2}{2n} \right)} \quad (2)$$

with the pre-post correlation set at $r = 0.50$. Because individual-level data were not available, r could not be estimated from the sample; a sensitivity analysis over $r \in [0.3, 0.7]$ is reported below. Paired t statistics were approximated using

$$SD_{diff} = \sqrt{SD_{pre}^2 + SD_{post}^2 - 2r \cdot SD_{pre} \cdot SD_{post}}.$$

Between-technique comparison. Postoperative values were compared pairwise by Welch's unequal-variance t test with Satterthwaite degrees of freedom, and the corresponding Cohen's d was computed with the pooled standard deviation. No multiplicity adjustment was applied; nominal p -values are reported and interpreted alongside effect sizes.

Principal component analysis. The six group-phase

profiles (three groups $\times$ two phases) were arranged as a 6×8 matrix, each column standardised to zero mean and unit variance, and decomposed by singular value decomposition. Component scores and loadings were retained for the first two components. Because the analysis operates on group profiles rather than individual patients, it characterises the geometry of the mean urodynamic state and not between-patient variation.

Software. Computations were performed in Python 3.12 with NumPy 2.4 and SciPy 1.17; the original clinical data were processed in Statistica 11.3 and Excel. The significance level was set at 0.05.

Ethics. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee of [institution], protocol No. [number] of [date]. Informed consent was obtained from the legal guardians of all patients.

3. Results

Baseline and postoperative values are given in Table 1.

Table 1. Urodynamic variables before and after valve ablation (mean $\pm$ SD)

Variable	Group I (n = 32)		Group II (n = 49)		Group III (n = 61)	
	pre	post	pre	post	pre	post
V _{max} , ml	162.7 $\pm$ 37.2	147.5 $\pm$ 31.9	164.7 $\pm$ 32.6	169.0 $\pm$ 26.9	190.2 $\pm$ 35.0	160.6 $\pm$ 16.4
h _w , cm	0.62 $\pm$ 0.08	0.54 $\pm$ 0.05	0.57 $\pm$ 0.04	0.51 $\pm$ 0.03	0.59 $\pm$ 0.07	0.50 $\pm$ 0.04
S _u , cm ²	0.30 $\pm$ 0.04	0.47 $\pm$ 0.04	0.30 $\pm$ 0.02	0.47 $\pm$ 0.02	0.31 $\pm$ 0.03	0.50 $\pm$ 0.03
V _r , ml	45.1 $\pm$ 19.4	11.2 $\pm$ 7.2	40.7 $\pm$ 11.7	9.1 $\pm$ 1.6	40.5 $\pm$ 12.4	8.9 $\pm$ 2.3
Q, ml/s	6.98 $\pm$ 0.88	13.42 $\pm$ 0.81	8.17 $\pm$ 1.78	12.67 $\pm$ 0.96	7.52 $\pm$ 0.74	15.36 $\pm$ 5.60
p _{det} , cmH ₂ O	34.9 $\pm$ 2.1	43.7 $\pm$ 0.5	37.4 $\pm$ 3.6	44.8 $\pm$ 0.3	36.3 $\pm$ 1.9	49.5 $\pm$ 0.4
T _d , a.u.	197.3 $\pm$ 20.4	254.4 $\pm$ 19.1	224.2 $\pm$ 30.1	276.7 $\pm$ 15.1	217.0 $\pm$ 20.4	258.6 $\pm$ 17.6
K _u	0.28 $\pm$ 0.07	0.11 $\pm$ 0.06	0.27 $\pm$ 0.04	0.08 $\pm$ 0.02	0.22 $\pm$ 0.06	0.05 $\pm$ 0.02

Magnitude of postoperative change

Standardised mean differences are listed in Table 2 and displayed in Figure 1. Every variable except maximum bladder capacity showed an effect exceeding $|g| = 1.9$ in all three groups, well beyond the conventional threshold for a

large effect. The largest single effect was the increase in effective urethral cross-section in group II ($g = 8.37$; 95 % CI 6.66 to 10.07) and the increase in detrusor voiding pressure in group III ($g = 9.47$; 95 % CI 7.75 to 11.19).

Maximum bladder capacity behaved differently from the

remaining variables: it decreased moderately in group I ($g = -0.43$), did not change appreciably in group II ($g = 0.14$; confidence interval spanning zero) and decreased substantially in group III ($g = -1.07$). A reduction in a previously overdistended bladder is the expected direction of change after relief of chronic obstruction, and its magnitude was largest where the obstruction was most completely relieved.

Table 2. Standardised mean differences (Hedges' g) for postoperative versus preoperative values, with 95 % confidence intervals

Variable	Group I		Group II		Group III	
	g	95 % CI	g	95 % CI	g	95 % CI
$V_{\max}$	-0.43	-0.79 to -0.07	0.14	-0.14 to 0.42	-1.07	-1.39 to -0.75
h_w	-1.17	-1.62 to -0.72	-1.67	-2.11 to -1.23	-1.56	-1.94 to -1.18
S_u	4.15	3.05 to 5.24	8.37	6.66 to 10.07	6.25	5.10 to 7.41
V_r	-2.26	-2.93 to -1.60	-3.71	-4.51 to -2.92	-3.50	-4.17 to -2.82
Q	7.43	5.53 to 9.33	3.10	2.41 to 3.78	1.94	1.51 to 2.37
$p_{\det}$	5.58	4.14 to 7.02	2.89	2.24 to 3.53	9.47	7.75 to 11.19
T_d	2.81	2.03 to 3.60	2.17	1.66 to 2.69	2.16	1.69 to 2.62
K_u	-2.54	-3.27 to -1.82	-5.91	-7.14 to -4.69	-3.75	-4.47 to -3.03

Confidence intervals computed with an assumed pre-post correlation $r = 0.50$.

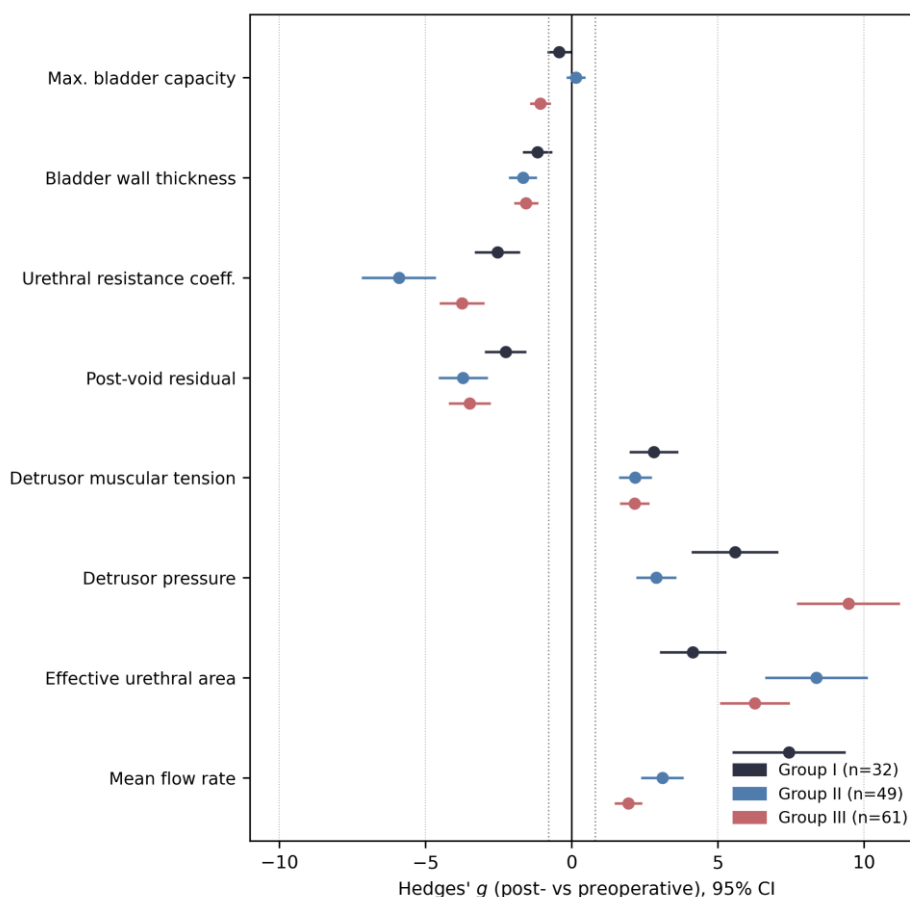


Figure 1. Standardised mean differences with 95 % confidence intervals for postoperative versus preoperative urodynamic variables. Dotted vertical lines mark $|g| = 0.8$.

A sensitivity analysis over the assumed pre-post correlation showed that point estimates of g are unaffected by r , since equation (1) does not involve it; only interval widths change. Setting $r = 0.30$ widened all intervals by a factor of 1.18, and $r = 0.70$ narrowed them by a factor of 0.77. No confidence interval crossed zero at $r = 0.30$ except that for maximum bladder capacity in group II, so the qualitative conclusions do not depend on this assumption.

Comparison between techniques

Pairwise comparisons of postoperative values are given in

Table 3. Post-void residual volume did not differ between any pair of techniques ($p \geq 0.12$), despite very large within-group reductions in all three. Urethral resistance, in contrast, separated all three techniques: the metallic valvulotome produced lower resistance than the polyethylene valvulotome ($d = 1.50$, $p < 0.001$) and than endoscopic resection ($d = 1.55$, $p < 0.001$), and endoscopic resection produced higher resistance than the polyethylene technique ($d = 0.74$, $p = 0.010$). Effective urethral cross-section was larger after metallic valvulotome ablation than after either alternative ($d = 0.89$ and 1.15), and mean flow rate followed the same ordering.

Table 3. Pairwise comparison of postoperative values between techniques (Welch test)

Variable	I vs II		I vs III		II vs III	
	d	p	d	p	d	p
$V_{\max}$	-0.74	0.003	-0.57	0.036	0.39	0.059

Variable	I vs II		I vs III		II vs III	
	d	p	d	p	d	p
h _w	0.77	0.004	0.92	< 0.001	0.28	0.137
S _u	0.00	1.000	-0.89	< 0.001	-1.15	< 0.001
V _r	0.45	0.115	0.49	0.092	0.09	0.646
Q	0.83	< 0.001	-0.42	0.010	-0.64	< 0.001
p _{det}	-2.89	< 0.001	-14.00	< 0.001	-13.91	< 0.001
T _d	-1.33	< 0.001	-0.23	0.302	1.10	< 0.001
K _u	0.74	0.010	1.55	< 0.001	1.50	< 0.001

Positive d indicates a higher value in the first-named group. p-values are nominal and not adjusted for multiplicity.

Dimensional structure of the urodynamic profile

Principal component analysis of the six group-phase profiles produced a first component accounting for 86.1 % of the total variance and a second accounting for 10.8 %; the remaining components together accounted for 3.1 %. The loadings on the first component (Table 4) fall into two opposed blocks of nearly equal magnitude: post-void residual (0.378), wall thickness (0.366) and urethral

resistance (0.372) on one side, and cross-sectional area (-0.377), flow rate (-0.377), detrusor pressure (-0.373) and detrusor tension (-0.359) on the other. This is the signature of a single underlying quantity — the degree of outlet obstruction — expressed in seven correlated variables. Maximum bladder capacity loaded only 0.181 on the first component but 0.945 on the second, confirming that bladder capacity carries information largely independent of the obstruction axis.

Table 4. Loadings on the first two principal components

Variable	PC1 (86.1 %)	PC2 (10.8 %)
V _{max}	0.181	0.945
h _w	0.366	-0.179
S _u	-0.377	-0.034
V _r	0.378	-0.005
Q	-0.377	-0.078
p _{det}	-0.373	0.036
T _d	-0.359	0.188
K _u	0.372	-0.175

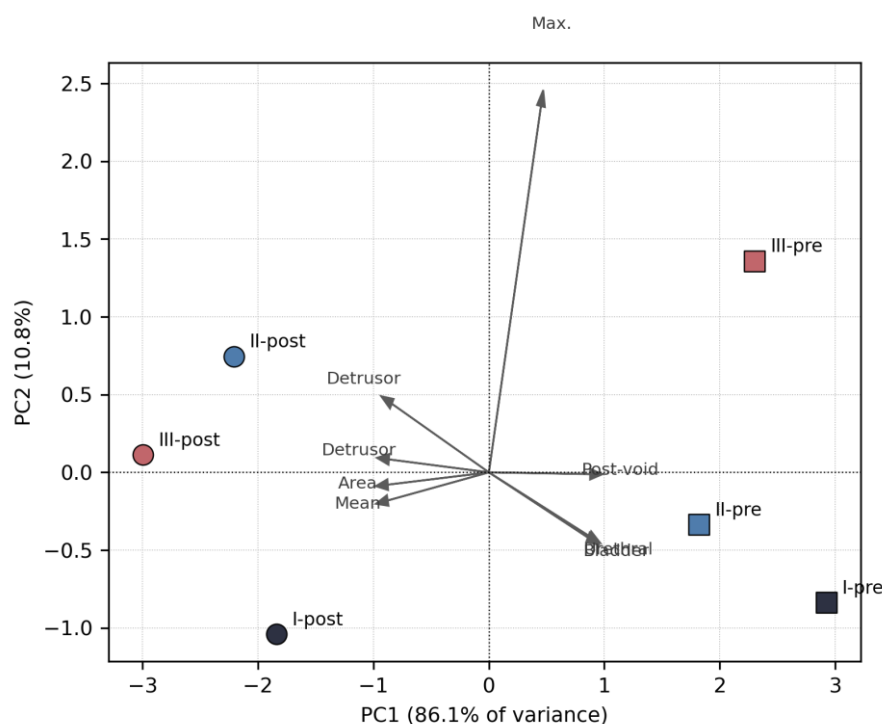


Figure 2. Principal-component biplot of the six group–phase profiles. Squares denote preoperative and circles postoperative states; arrows show variable loadings.

All three preoperative states occupy the positive half of the first axis (scores 1.82 to 2.92) and all three postoperative states the negative half (−1.84 to −3.00), so that the operation amounts to a translation along this axis. The displacement was 5.30 units for the metallic valvulotome, 4.76 for endoscopic resection and 4.03 for the polyethylene valvulotome. The postoperative state furthest from the obstructed region was that of group III (−3.00).

4. Discussion

Two findings have direct practical consequences. The first is that post-void residual volume, although it changes dramatically with surgery in every group, does not distinguish between techniques: postoperative values of 11.2, 9.1 and 8.9 ml are statistically indistinguishable given the observed dispersions. A residual volume close to zero is achieved once the obstruction falls below some threshold, and further improvement in outflow does not reduce it further. Using residual volume as the primary endpoint of a technique comparison would therefore be uninformative, whereas urethral resistance and flow rate retain discriminating power throughout the range.

The second is the near-unidimensionality of the urodynamic profile. That 86 % of the variance of eight variables is captured by one component means that seven of them

convey essentially one piece of information. This supports the long-standing practice of summarising bladder outlet function by a single index [8–11] and suggests that a composite score built as a weighted sum of the standardised variables, with weights proportional to the first-component loadings, would be more efficient than any single variable. It also implies that the apparent richness of an eight-variable urodynamic report is partly illusory, and that reporting multiple significance tests on such variables inflates the impression of independent evidence.

Maximum bladder capacity is the exception. Its near-orthogonality to the obstruction axis, and its divergent behaviour across groups, are consistent with the view that bladder capacity after valve ablation reflects a distinct process — remodelling of a chronically overdistended detrusor — that follows its own time course [4, 5, 12]. A reduction in capacity after successful relief of obstruction should therefore not be read as deterioration.

The ordering of techniques obtained here by three independent routes — the postoperative resistance coefficient, the pairwise comparisons and the displacement along the first principal component — is the same in each case, with metallic valvulotome ablation ranked first. The convergence is reassuring but not independent evidence, since all three analyses use the same measurements. The one

apparent inconsistency, the very large within-group effect for cross-sectional area in group II ($g = 8.37$, the largest in the series), arises from an unusually small standard deviation in that group rather than from a larger absolute change: the absolute increase was 0.17 cm^2 in both groups I and II and 0.19 cm^2 in group III. This illustrates the complementary nature of standardised and unstandardised measures, and the importance of reporting both.

The very large effect sizes across the series, several exceeding $g = 5$, deserve comment. Values of this order are rarely seen in clinical research and reflect the relief of a mechanical obstruction, where the postoperative distributions barely overlap the preoperative ones. They should not be compared with effect sizes from studies of pharmacological interventions.

5. Limitations

The analysis was performed on aggregate rather than individual-level data. This has three consequences: the pre-post correlation had to be assumed rather than estimated; the principal component analysis operates on six group profiles rather than 142 patient profiles and therefore describes the geometry of the mean state, with the proportion of variance explained not transferable to between-patient variation; and no adjustment for baseline differences or covariates was possible. Baseline maximum bladder capacity and urethral resistance did differ between groups, and since allocation was not randomised, confounding by indication cannot be excluded. The dispersion values in the source data were interpreted as standard deviations; if they represent standard errors, all effect sizes would scale by $(\sqrt{n})$. The unit of intravesical pressure requires confirmation from the primary records. Follow-up duration, renal function and continence outcomes were not available, and the analysis therefore speaks only to immediate urodynamic performance.

6. Conclusions

Valve ablation produces very large urodynamic effects by all three techniques, but the techniques are not equivalent. The urodynamic response is essentially one-dimensional, with a single component accounting for 86 % of the variance of eight variables; displacement along this component was greatest after metallic valvulotome ablation. Post-void residual volume saturates and cannot discriminate between techniques, whereas urethral resistance and flow rate can. Future comparative studies of PUV ablation should report effect sizes with confidence

intervals alongside p-values, and should select endpoints that retain discriminating power in the range where the techniques actually differ.

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